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BASE CAMP DESIGN: SITE SELECTION AND FACILITY LAYOUT

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If you can figure out the criteria for base camp selection…you've done something the Army can use. – LTG Flowers, Chief, US Corps of Engineers (2 May 2001)

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14. ABSTRACT

Army deployments to conduct operations other than war have been sustained by base camps for 225 years. In other words, base camp development is not a new endeavor. However, the larger footprint required by the logistical demands of modern equipment coupled with deployments in urban regions have created an environment where site selection and facility layout within a base camp become difficult problems. Increased environmental awareness, new construction standards to address force protection and soldier morale, and life-cycle cost make base camp location and layout an important Army issue. Therefore, base camp design, management and reengineering should proceed from a systems engineering perspective in order to adequately address these complex and interrelated requirements

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TABLE OF CONTENTS

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EXECUTIVE SUMMARY

A better primer or planning guide for the design, construction, and sustainment of base camps must be developed. This must be an integrated product that includes general engineering considerations, field sanitation, force protection concerns, and environmental-related considerations. -- Colonel Michael A. Hiemstra, Director, Center for Army Lessons Learned

Up front to this whole effort there needs to be some sort of setting the stage- for the theater and political leadership - to understand what it means when we say we are going to deploy and base troops for a time (months to years), on foreign soil. We all must come to agreement that it means this in terms of living conditions, this in terms of support (eveything from hospitals to AFN), etc., etc. I've often argued we need an Army wide "son of Red Book", that when a decision is made to put troops into Sierra Leone or
Bosnia, it will mean this; it will mean that.– Colonel Robert McClure, 1st Engineer Brigade, 1st ID (M)

Army deployments to conduct operations other than war have been sustained by base camps for 225 years. In other words, base camp development is not a new endeavor. However, the larger footprint required by the logistical demands of modern equipment coupled with deployments in urban regions have created an environment where site selection and facility layout within a base camp become difficult problems. Increased environmental awareness, new construction standards to address force protection and soldier morale, and life-cycle cost make base camp location and layout an important Army issue. Therefore, base camp design, management and reengineering should proceed from a systems engineering perspective in order to adequately address these complex and interrelated requirements.

The Army has numerous field manuals, technical manuals and policy documents that discuss techniques, standards, and requirements for base camp construction. However, military planners do not have doctrinal guidance, an information repository, or a decision support tool to aid commanders in selecting the best locations for base camps. Location decisions are usually based on tactical considerations derived from intelligence preparation of the battlefield (IBP) for the deployment and anticipated OOTW missions. Typically, a unit arrives and occupies an assembly area. Over time the location evolves into a de`facto base camp location. Military planners would also benefit from a decision support tool that optimizes the facility layout for a base camp location while providing flexibility for modification and expansion. This executive summary presents our progress in determining base camp functions and the very specific knowledge requirements for base camp site-selection and facility layout. It concludes with a discussion about the future research, highlighting the system requirements for the decision support system.

A first step in addressing this problem is to clearly define a base camp and identify its primary functions. To this end, we define a base camp as an evolving military facility that supports the military operations of a deployed unit and provides the necessary support and services for sustained operations. Using this definition, a base camp's primary function is mission support. To accomplish this support, it must provide four key services: force protection, critical infrastructure, training support, and maintenance support. A functional decomposition of these services provides insight for base camp location and facility layout decisions. Force protection programs must safeguard and secure people, facilities, equipment, supplies, transportation networks, and information. These programs must adapt to the threat, mission, and environment.

Classifying the critical infrastructure will help managing the base camp real estate by creating zones similar to those used by city master planners. Typical base camp infrastructure can be classified as housing, soldier support, unit support, and morale-welfare-recreation. Housing is further defined by type such as tent or sea hut. Unit support is decomposed into elements that include motor pools, unit headquarters, electric power, water (potable and treatment), road networks, fuel storage, and ammo holding areas. The soldier support component is representative of areas in the base camp dedicated to dining facilities, aid stations, chapels, education center, postal service center, mail rooms, finance support, barber, post exchange, food concession and fire protection. The morale-welfare-recreation component is comprised of fitness centers, theater center, common areas, library, TV rooms, athletic fields, and running trails. OOTW missions make individual and collective training support critical. Units need areas to train on tasks they may not normally perform. They also require training resources to maintain proficiency on essential tasks that they probably will not perform in theater. Equally important is providing maintenance areas and facilities to support equipment and facility. These component lists for the four critical services are not exhaustive and are a function of resources, politics and time. In general, the larger the facility and length of deployment will impact on the number and types of facilities. The important point is that stakeholders desire quality of life for deployed soldiers and theater commanders establish the guidelines on facilities. A few more components of the definition need emphasis. A base camp supports a deployed unit. Although the camp may have permanently assigned personnel, the units will rotate through the facility. The next point is that the base camp provides for sustained operations. This implies a requirement for continuous re-supply and the establishment of a logistical support structure.

Although assembly areas may provide many of the services in austere base camps, they usually lack the ability for sustained logistical support.

Stakeholders are individuals who can influence decision outcomes. They are key players-- internal or external to an organization and either controllable or uncontrollable. Since base camp location is closely coupled with early decisions on assembly area location, deploying units would benefit from a system that incorporates environmental, political, economic, geographic, and infrastructure considerations. The most obvious stakeholders are commanders and their staffs. These headquarters range from the Commander-in-Chief of a unified command to the units occupying and supporting a base camp. The commanders are responsible for decision-making, and their staffs must provide them with adequate information to make the decisions. The principle staff agencies include those responsible for personnel, operations, engineer, logistics and resource management functions. These agencies desire a fair and equitable quality of life consistent with resource, political, and military constraints. Additional staff stakeholders are those who levy requirements on the location and layout of base camps. For example, signal officers have a stake because of the impact of communications: satellite, FM, HF, email, etc. There also agencies that are not in the chain of command that impose requirements on the base camp location and design. Safety officers from DOD agencies have a stake because they certify the base camp as safe. DOD Antiterrorism Force Protection (AT/FP) Program implements a Joint Staff Integrated Vulnerability Assessments (JSIVA) to review installation AT/FP programs. The JSIVAs look at physical security measures, AT/FP training, operational intelligence fusion, structures, and plans for responding to terrorist incidents. In fact, there are a host of outside agency stakeholders (with requirements) that have an impact on location and layout. Contract personnel, host nation governments, local populations, United

Nation agencies, non-governmental organizations, environmentalist, and local industries are a few examples.

Developing a common language is critical to facilitate future base camp discussion, research, planning, and execution. Aside from acknowledging the basic functions and components, base camps should also be classified in terms of states, hierarchical structure and lifecycle. The "state of the system" is a time-dependent description that captures the operational essence of the system (base camp). The operational states of the base camp may be viewed in terms of capability and lifespan. Capability can be characterized by commonly used schemes such as mission capable, non-mission capable and fully mission capable or red, amber, and green. The construction state is characterized as temporary or permanent.

A convenient manner to address hierarchy is to characterize the system in terms of base camp type or level of command. They are three types of base camps: major base camp, remote site, or forward operating site. Additionally, one can identify a base camp or system of base camps by command level. Commands levels are geographic combatant, area, base camp cluster, tenant, remote site, or forward operating site commander. Finally, base camps should be understood in terms of lifecycle. We identified nine lifecycle functions for base camps: deciding, designing, locating, constructing, operating, maintaining, upgrading, deactivating, and retiring.

A prototype decision support system is in the early stages of design in the ORCEN. Based on stakeholder and needs analysis, we believe the system should support critical site location and facility layout decisions. The site selection prototype DSS (GeoBLAST) accepts inputs such as: user type, mission, area of operation, mission duration, alternative locations, value assignment to evaluation measures, and weight assignment to knowledge categories.

These inputs are transformed via a knowledge hierarchy and rule base implementation into system outputs, which include site selection, resource requirements, facility layout and general knowledge. Finally, the system provides layout configuration for the components of a base camp where the component selections are a function of force protection, base camp size, mission, duration, and unit type. After a year's research we present our accomplishments:

- Examined Joint and Army doctrine, producing a working definition of "Base Camp" that facilitates research into base camp site-selection and facility layout
- Identified a need for coherent and actionable doctrine (FM –Base Camp Operations)
- Developed a functional decomposition for base camps
- Described base camp lifecycle functions
- Identified multidisciplinary considerations for base camp site-selection and facility layout systems
- Implemented multidisciplinary capstones at USMA
- Published and presented research at various conferences
- Developed a web site for base camp research

The report is organized into two major sections. Section one comprises the research to date on site selection. Four papers were written on site-selection[1234] as well as two conference presentations (Society of American Military Engineers' National Conference June 2001 and Engineering Foundation Conference on Risk-Based Decision Making in Water Resources IX October 2000). Section one provides an overview of the prototype, GeoBLAST—Geographic

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[1] Barry C. Ezell, Mark J. Davis, and Michael L. McGinnis, "Designing A Decision Support System For Military Base Camp Site Selection And Facility Layout", Engineering Foundation Conference on Risk-Based Decision Making in Water Resources IX Proceedings, October 2000.

[2] Barry C. Ezell, Gregory Parnell, Yacov Y. Haimes, and James H. Lambert, "Designing an OOTW Decision Support System Military Planners", IEEE 2000 International Conference on Systems, Man and Cybernetics, October 2000 Proceedings.

[3] Greg Parnell, Barry C. Ezell, Yacov Y. Haimes, Kent Schlussel and Mark Sulcoski, "Designing a OOTW Knowledge Hierarchy for a OOTW Decision Support System for Military Planners", Phalanx: A Bulletin for the Military Operations Research Society, December, 2000.

[4] Barry C. Ezell, Mark W. Brantley, and Mark J. Davis, "Base Camp Design: Developing a Decision Support Tool for Site Selection and Facility Layout", Military Engineer, Vol. 93, No. 610, 2001.

Basecamp Layout and and Selection Tool. Section two of the report is dedicated to research on facility layout. One paper was written on facility layout and will be presented in October 2001[5]. This report is a compilation of work including the papers, meetings, and presentations over the 2000-2001 academic term in the ORCEN.

Over the next 18 months, cadets and faculty at the US Military Academy will deploy to several overseas locations collecting data for potential base camp locations in support of OOTW contingencies. Engineering capstone teams will use this data to refine decision-making models and instantiate knowledge bases useful to detailed planning within the specific geographic areas studied. On 10 September, 2001, Admiral Dennis Blair, CINCPAC will provide the key note remarks at the first annual base camp conference hosted by USMA and the Department of Systems Engineering.

[5] Matthew U. Robertson, Barry C. Ezell, and Michael L. McGinnis, "Base Camp Facility Layout", IEEE 2001 International Conference on Systems, Man and Cybernetics, to be published in the October 2001 Proceedings.

SECTION ONE: BASE CAMP SITE SELECTION

INTRODUCTION

Base camps are expensive to operate and maintain. There are several unrealized costs attributed to upgrading, transitioning to new tenants, and deactivating. For 225 years, the Army (with the assistance of host nation and contracted support) has employed base camps as support locations for forward deployed forces. In other words, base camp construction is not a new idea. What is new is the recent trend to outsource base camp operations (food, power, waste, etc.), and that outsourcing has proven to be expensive and wasteful. Outsourcing supplies and services is a result of the political need to minimize the number of US soldiers deployed in a theater. This creates the condition where the Army must rely on contracted support.

Military planners are routinely guided in their efforts by applicable field manuals, which define terms of reference and prescribe procedures by which to accomplish tasks and order priorities. Unfortunately, the Army has no field manual on base camp operations. Even worse, the term "base camp" is not defined in current military doctrine. There are volumes that guide individual building and facility design of technical specifications and theater-specific construction standards. Base operations are discussed in what is commonly referred to in the Engineering Corps as the "Blue Book" [USAREUR, Base Operations 1999]. Facility standards are detailed in the "Red Book" [USAREUR, Base Camp Facilities Standards 1999]. Field Manuals such as 5-104, General Engineering, [Army Field Manual 5-104 1986] provide some information on what a base camp should accomplish, but again, there is no capstone doctrine. In our view, the Army would benefit from a capstone field manual on base camp operations in the same way the

services benefit from Joint Vision 2020 [JV2020] and Army capstone doctrine such as Field Manual 100-5, Operations [Army Field Manual 100-5 1993].

Stakeholders

In this paper, we define stakeholders as individuals and agencies who can directly or indirectly influence the decisionmaker and impact on decision outcomes. Stakeholders are key players who are internal or external to our organization and either controllable or uncontrollable. For our analysis, we determined that the Commander-in-Chief (CINC) of a unified command with an area of responsibility (e.g., CENTCOM, EUCOM, PACOM, or SOUTHCOM) is the ultimate decisionmaker for any system we design. We believe CINCs desire a system that will aid their staffs in determining the best locations for base camps and facility layouts. High-level users are principle staff agencies represented by the deputy chiefs of staff for personnel, operations, engineers, logistics, and resource management. These agencies, according to the Blue Book, desire: "a fair and equitable quality of life consistent with available resources and political and military considerations." Deploying units are also stakeholder groups. They are represented by commanders and staff who desire a system that provides decision support for base camp locations and facility layouts, as well as considerations for mission and force protection. Since base camp location is closely coupled with early decision on assembly area location, deploying units would benefit from a system that incorporates environmental, political, economic, geographic, and infrastructure considerations.

WHAT IS BASE CAMP?

The term base camp is not defined in military doctrine. JP 1-02 [1997] defines base as a locality from which operations are projected or supported. It also defines base as an area or

locality containing installations that provide logistic or other support. Army Field Manual 101-5-1 [1997] defines base as a grouping of units or activities within a defined, defensible perimeter with specific access-control points and traffic control, where all units or activities are under the operational control of a single commander for security operations. Camp is defined in JP 1-02 [1997] as a group of tents, huts, or other shelter set up temporarily for troops, and more permanent than a bivouac, including a military post, temporary or permanent. Our systems engineering approach, anchored in functional decomposition, defines a base camp as an evolving military facility that supports the military operations of a deployed unit and provides the necessary support and services for sustained operations.

THE BASE CAMP AS A SYSTEM

A system can be defined as an arrangement of components or elements that work together to perform some useful purpose [Sage and Armstrong 1999]. A system can then be viewed in terms of functions, states, components, and structure. In the domain of base camp analysis, the top-level function is mission support, i.e., the support that a base camp system provides for the execution of the overall military mission of the deployed force. To execute mission support, a base camp must provide force protection to deployed forces, resource management of critical infrastructure, training opportunities for deployed forces and permanent party, and maintenance to facilities. Base camp life-cycle functional analysis and functional decomposition is described in the following section.

The "state of the system" in systems engineering is often referred to as a time-dependent description that captures the operational essence of the system (base camp, in this case). Base camp capability can be characterized as non-mission-capable, mission-capable, and fully mission-capable when evaluated in terms of the high-level functional description above. The

construction state is characterized as temporary or permanent [USAREUR Base Operations 1999].

It is important to note that the overarching mission of the deployed force can change over time. In fact, any detailed analysis uncovers the time-phased "evolution" of the mission. The design of the base camp must account for this dynamic nature and possess a flexibility that allows its adaptation.

Hierarchical structure in systems includes super, adjacent, and subsystems. With respect to the base camp system, a convenient way to address hierarchy is to characterize the system in terms of command. Depending on the level and scope of command, one can identify a base camp as a function of command level and location (major base camp, remote site, or forward operating site) or type of command (geographic combatant commander, area commander, base-camp cluster commander, tenant commander, remote site, and forward-operating-site commander). System components or elements of a base camp are described in terms of base camp facilities [USAREUR, Base Operations 1999]. Facilities are organized into four types: housing, soldier-support, unit, and morale/welfare/recreation. Housing is further defined by type: for example, tent or sea hut. Unit is decomposed into twelve elements, such as motor pool and organizational unit (i.e., company, battalion, brigade). The unit component also contains typical critical infrastructures: electric power, water (potable and treatment), road networks, fuel storage, and ammo holding areas [USAREUR, Facility Standards 1999]. The soldier-support component represents areas in the base camps dedicated to dining facilities, aid stations, chapel, education center, postal service center, mail room, finance support, barber, post exchange, food concession, and fire protection. The morale/welfare/recreation component is comprised of fitness center, theater center, common areas, library, TV rooms, athletic fields, and running trails.

The component list is not exhaustive. Decisions on facilities made available for soldiers are a function of resources, politics, and time. In general, the size of the force and length of deployment will impact on the number and types of facilities. The important point is that stakeholders desire a good quality of life for deployed soldiers, and theater commanders establish the guidelines on facilities.

FUNCTIONAL DECOMPOSITION

In order to better understand base camp operations, systems engineers often functionally decompose a system. There are four top-level functions:

- force protection,
- resource management,
- collective and individual training, and
- maintenance.

Force protection includes programs that safeguard and secure people, facilities, and equipment. Resource management includes management of the infrastructure and facilities of a base camp. This is decomposed into ten subordinate functions. Training is characterized as collective or individual. The decomposition refers to the typical training activities common to any base camp. The final top-level function is maintenance. This is decomposed into equipment, environment, facilities, and readiness. Functional decomposition provides insight into considerations for base-camp location and facilities layout.

In this section we defined the problem and established the critical stakeholders and described the systems in terms of functions, components, states, and hierarchy. In the following section we describe the inputs, outputs, process flows for GeoBLAST, a decision support system.

SUPPORT TO DECISIONMAKING PROCESS

GeoBLAST provides support to critical site location and facility layout decisions. Site-selection includes geographic location, dimensions, and geo-spatial information for surrounding critical infrastructures. Finally, the system provides a layout configuration for the components of a base camp where the component selections are a function of force protection, camp size, mission, duration, unit type, and other factors (see Figure 1).

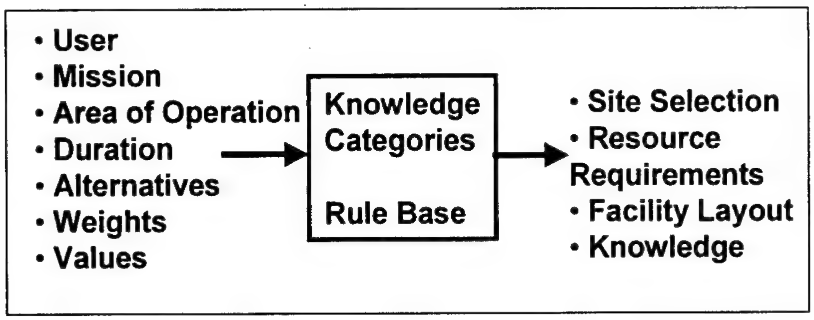

Figure 1. Basic input-output model for decision support system.

DECISION SUPPORT SYSTEM PROCESS FLOW

In designing GeoBLAST, we decided that the primary inputs by the user would be user type, mission, area of operation, mission duration, alternative locations, value assignment to evaluation measures, and weight assignment to knowledge categories. In turn, these inputs would be transformed via the knowledge hierarchy and rule base into system outputs: site selection, resource requirements, facility layout, and general knowledge (Figure 1).

Figure 2 describes the user's interaction and flow with the system. The interaction can be summarized as follows. First, the user type is self-selected from a menu of choices (e.g., brigade operations officer, logistics officer). Next, the user chooses the mission type from one of 13 operations other than war. The system presents the five unified command areas of responsibility and the user chooses the area of operation. Once these parameters are

established, the system presents maps of the area that allow the user to select alternative locations. Based on these alternatives, the system presents a series of evaluation measures, eliciting value assignments for each. (A definition list of evaluation measures may be found in the model GeoBLAST.) Upon conclusion of value assignment, the user selects weights for each knowledge category. The best site location is then calculated based on the value score and weight via an additive preference model. The location with the best overall score is the best site. The system then allows the user to "peel back" each score to analyze how the overall score was obtained. GeoBLAST is a hybrid system that uses three programming tools: a database (FileMaker Pro, spreadsheet (MS Excel) and a simulation add-in (CrystalBall 2000). FileMaker manages the data and provides a user interface. FileMaker passes data via an ODBC connection. Excel accepts the input from FileMaker and uses those inputs for the simulation in Crystal Ball.

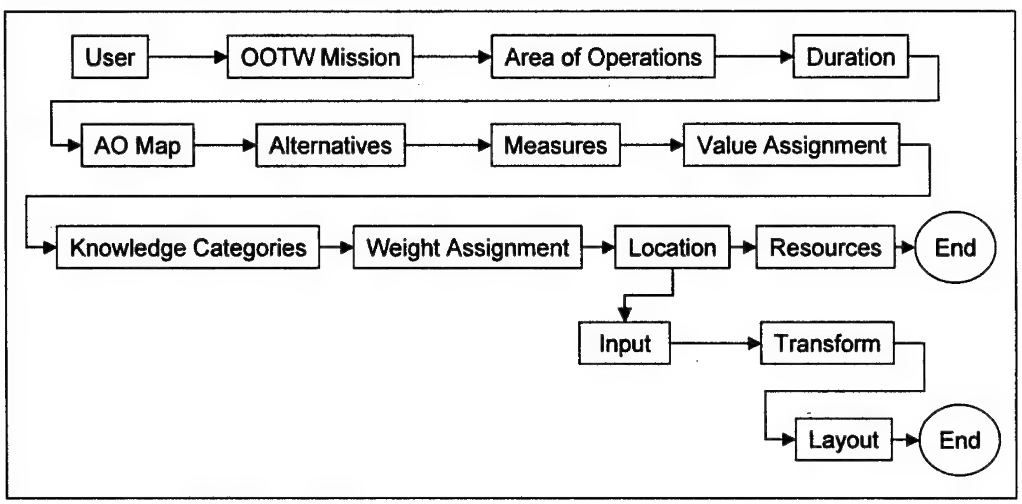

Figure 2. Decision support system process flow.

Figure 3 depicts the entire flow including screen shots of the system.

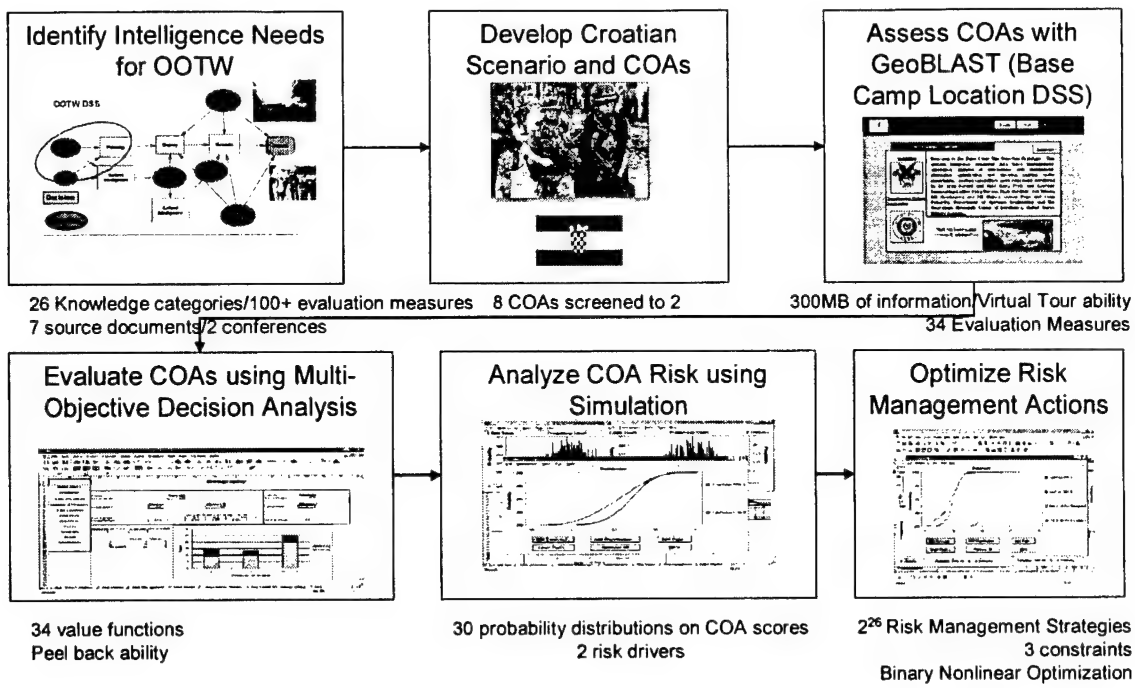

Figure 3. GeoBLAST Consultation Overview

MODELING SCENARIO

GeoBLAST is a prototype that focused exclusively on Slunj, Croatia. There were two reasons that Slunj was chosen. One of our students working the project was an exchange student from Croatia. Secondly, the American Embassy in Croatia was very supportive to assisting us in studying the considerations for base camp location in Croatia. A brief summary of the scenario follows in the next section.

CROATIA SCENARIO

As a result of the five-year war for Croatian independence, thousands of Croatians are protesting against war crimes investigations into several former generals who fought in the War for the Croatian independence (1990-1995).

During the previous government, when Tudjman was the President, Croatians were exclusively represented as victims in the Serb-Croat war of 1991. However, the new government's attempt to shed light on possible atrocities committed against Serbs, has caused great contempt between many of Croatian citizens.

Some 30,000 Croatians of all ages gathered at the main square in Split, a town located in Southern Croatia on 22 April 2001. Another demonstration was held in the Eastern Croatian, in the town of Osijek on 23 April 2001. Protesters became increasingly violent leading up to the demonstrations. These demonstrations were the latest confrontations between the one-year-old pro-democracy government and its predecessor (HDZ), but also the sign of a great economic instability of Croatia. Several riots, acts of vandalism, and ethnic struggles resulted because of the demonstrations and economic situation. These activities have become increasingly rampant in the region, so frequent and out of control that the Croatian Police force can no longer control the situation.

Organizers (believed to be backed by HDZ, the main nationalist opposition party) hired a state railway train to bring protesters from Zagreb and all across the country. Buses and cars had brought more people from across the border in Bosnia already. The Croatian government and its President, Stipe Mesic, have gone increasingly weary of its ability to stop the influx of demonstrators and fear the Muslims, Bosnians, and Serbs could become involved to the extent of extreme ethnic violence. President Stipe Mesic requested a conference from the United Nations in Geneva, Switzerland on 31 April 01 to request immediate assistance for the destabilizing situation in the region. In response, several representatives of the UN, including the United States' UN Commissioner for UNMOVIC, Robert Einhorn, were sent to discuss alternative actions to stabilize the region before the situation resulted in a conflict, i.e. civil war, etc.

President Stipe Mesic claimed that the protests and riots were aimed at destabilizing democracy and once again isolating the country from the Western Europe. President Sitpe Mesic stated that if the UN did not get involved the situation would indeed erupt into a civil war or war between the countries of former Yugoslavia are likely plausible. President Stipe Mesic presented clear evidence that paramilitary groups are bringing illegal weaponry into the region in preparation for possible conflicts with Croats and the Croatian government.

On 2 May 2001, President Mesic requested international assistance to help his government restore peace in the region. After contentious debate, the UN determined that a peacekeeping operation was necessary in order to stabilize the region, stave off war, and maintain the current legitimacy of the Croatian government. The UN turned to the predominate members of the Security Council to provide the PK force.

President Bush responded by ordering military forces into the region no later than 29 May 01. The PK force will deploy in the vicinity of Slunj to control the avenues of approach north-east in and out of Slunj to Zagreb and control the southwest border with Bosnia. The President made it clear that the political objective is to promote order and stability in the region by dealing with the tension and violence without becoming a participant.

After recommendations from the SECDEF, Donald Rumsfield, the 52ID's 1st IBCT was chosen to deploy to the region.

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SECTION TWO: FACILITY LAYOUT

INTRODUCTION

Base camps have been in the Army's repertoire since its formation. A base camp is an evolving military facility that supports the military operations of a deployed unit and provides necessary support and services for sustained operations [1]. Because of the recent proliferation of deployments, the Army now uses base camps from Haiti to South America to Kosovo. These camps usually begin as tactical assembly areas and become defacto base camps over time. This process calls upon the Army's engineers to develop and construct camp layouts that are tactically sound and help soldiers to complete their missions in less than ideal situations. Because of the increase in the number of Operations Other Than War (OOTW) deployments and the ever-increasing complexity of base camps, some type of layout optimization tool would be useful in planning and constructing base camps.

Unfortunately, no known recent work in the field of base camp layout optimization has been completed. This was the main motivator in studying base camp facility design. The Construction Engineering Research Laboratory (CERL) is currently attempting to optimize base camp layouts given terrain limitations using GEOBEST, a U.S. Air Force site location planning tool, but has yet to obtain suitable results. Other initiatives, such as the Contingency Facilities in Future Base Camps by the Office of the Chief of Engineers and capstone projects at the United States Military Academy, have an interest in finding an optimal base camp layout.

The purpose of this project was to aid in the development of a base camp facility layout optimization system by understanding the proximity relationships between base camp components, developing a facility layout domain, and comparing generated layouts to existing models and camps. The first phase involved collecting input from a variety of sources to gain an understanding of the proximity relationships between fifteen common base camp facilities. This

data was then entered into the Computerized Relative Allocation of Facilities Technique (CRAFT) software in order to generate a camp layout. The final phase involved comparing the results to mid-1980s Theater Construction Management System (TCMS) drawings and Camp Bondsteel's layout.

DATA COLLECTION AND TRANSFORMATION

To optimize a base camp the facilities, or components, which make up the physical infrastructure of a base camp must be arranged in the most efficient manner. Some common types of facilities include motorpools, chapels, and ammunition holding areas. Both passive and active research methods were used to collect data about base camp facility proximity relationships. Two passive methods, research of military publications and web-based research, were used to obtain general information about the relationship between various facilities. Overall, one-third of the data came from passive research. An online survey of critical stakeholders and interviews with a commander of an engineer brigade constituted the active research portion of the project and filled in gaps left by the passive methods. Two-thirds of the data came from this type of research. The end result of this phase was a completed relationship chart for a base camp with 15 different facilities.

PASSIVE DATA COLLECTION

The first data collection stage involved intensive study of the U.S. Army Europe Engineer's Red Book and Blue Book. These sources outlined individual facility standards. Specifically, the Red Book contained a detailed listing of common base camp facilities and their minimum acceptable standards [2]. The Blue Book was intended to provide commanders and soldiers deployed to the Balkans a definitive guide to the extent and quality of base operations,

products, and services they could expect while in garrison [3]. Both sources helped in the determination of the primary components of a major base camp. From over 30 types of facilities listed in these sources, 15 were chosen for the study. This number represented a compromise between a realistic base camp, a reasonable optimization calculation time, and available information..

Research on the World Wide Web constituted the second type of passive research. Many base camps and units deployed to base camps have their own web pages. Additionally, online articles documenting successes and failures of various base camps were plentiful. Although these sources were useful in gaining a general understanding about base camp layouts, they provided little information directly related to facility layout.

ACTIVE DATA COLLECTION

In order to address some of the layout shortcomings of web resources and the Red and Blue Books, correspondence was initiated with Colonel Robert McClure, Commander, 1st Infantry Division Engineer Brigade (mechanized). His responses answered numerous questions about the relative positioning and number of facilities per base camp. Additionally, he cited certain components such as motorpools, ammunition holding areas, and fuel storage areas that should be separated from populated areas of the camp [4].

Despite obtaining information from Army publications, web research, and an interview with a base camp expert, there were still some unresolved facility proximity issues. In some instances, proximity relationships between components could not be found. In other instances, conflicting information about component relationships existed. To resolve these issues, an online survey was created. Nineteen questions such as:

How important is it for Seahut Clusters (housing are) and Aviation Facilities to be close in proximity?

were asked. The users were asked rate the importance of proximity between various base camp facilities on a scale of 1 (avoid at all costs) to 10 (extremely vital). A response of 5 signified that adjacency was unimportant. Twelve respondents, consisting of a good blend of civilian and military experts from Kansas to Kosovo, responded. The variety of respondents naturally led to wide variety of responses. Coupled with a small sample size, high response variances were prevalent.

Because of response variety and the small sample size of the survey, determining a single good measure of central tendency was difficult. Although the mean is usually the preferred statistic in measuring the central tendency of samples, the sample size of this survey was small and thus susceptible to outliers. An answer to outlier susceptibility was the median. The final measure of central tendency, the mode, represented what would have occurred if the stakeholders voted on the relationship between the facility proximity. Since the mean, median, and mode each had advantages in measuring facility proximity relationships, they were calculated for each question and later used to generate three different base camp layouts.

DATA TRANSFORMATION

All of the data collected was eventually placed into relationship charts, a convenient way to organize data. A standard technique, which can be found in major Operations Management texts such as Heizer and Render's Operations Management, was utilized [5]. If close proximity of base camp components was absolutely necessary, the cell corresponding to the components relationship received an A. If the proximity relationship was especially important, the cell received an E. Important relationships received an I, Okay relationships received an O,

Unimportant relationships received a U, and Undesirable relationships received an X. Through the passive research methods Colonel McClure's interviews it was fairly easy to discern and code facility proximity relationships.

The survey data required a more concerted transformation effort, though. The absolute highest and lowest values for any of the three measures of central tendency were 10 and 1, respectively. Score brackets were created to transform these numerical values into a relationship chart values. For instance, a survey score between 9 and 10 received an A, while a score between 1 and 3 received an X. Because of the difference between the mean, median, and mode responses, certain questions had three different letters, one for each of the three measures. Of the nineteen questions asked, eleven received at least two different letters depending on the measure of central tendency used in the calculation.

Because of the differences amongst the survey responses and subsequent central tendency measures, there was a need to create three separate relationship charts. These charts were titled Mean, Median, and Mode based on where their survey data came from (see figure 1). 37% of the survey data within the relationship charts was different in at least one of the charts. One-third of the data within the charts came from non-survey data and was thus similar. An additional 30% of the data came from the survey and was identical for each relationship chart.

Component #	Component Name	Mean Alternative	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Seahut Clusters	1		X	X	X	E	I	I	I	I	E	I	E	X	O	I
2	Motorpools	2			U	X	X	X	X	X	X	X	X	X	X	U	O
3	Aviation Facilities	3				U	U	U	U	U	U	U	U	U	X	U	O
4	Ammo Holding Area	4					X	X	X	X	X	X	X	X	U	X	X
5	Mess Halls	5						O	O	O	O	O	O	O	X	O	O
6	Chapels	6							O	O	O	U	O	O	X	O	O
7	Education Center	7								I	I	O	I	I	X	I	O
8	Postal Facility	8									U	O	U	O	X	I	O
9	SSA Facility	9										O	U	O	X	O	O
10	Personal Services Centers	10											I	I	X	I	O
11	PX	11												I	X	I	O
12	MWR Facilities	12													X	I	O
13	Fuel Storage Area	13														X	X
14	Laundry Collection Point	14															O
15	Aid Station	15															

Figure 1: Relationship Chart for the *Mean* Alternative

MODELING

After the data had been collected and organized into three relationship charts, some type of optimization was needed to determine the best layouts. The desired software package was one that would find the optimal layout given fifteen different components and their proximity relationships. Unfortunately, no readily available software with this capability was found. Three different alternatives were tried, but only one provided acceptable results. The following section describes the issues encountered using Production and Operations Management for Windows, Excel OM, and CRAFT software to find the optimal layout strategy for a 15 facility base camps.

MODELING ALTERNATIVES

The first attempt at layout optimization used Production and Operations Management (POM) for Windows [5]. POM is an operations management tool focused on a variety of operation management problems, not just facility layout. The facility layout module gives the user the option of using pairwise comparisons or explicit enumeration to find the optimal layout. Using the pairwise comparison method, POM minimizes the product of the proximity scores from the relationship chart and rectilinear distances between components. This method is quicker than using explicit enumeration, which checks all n! layouts. However, it does not always find the optimal solution. POM was advantageous because it had the option of finding the optimal layout or using pairwise comparison and was easy to use. Unfortunately, POM was only capable of handling a layout with ten facilities, while software capable of handling fifteen was desired. Cutting the number of components to ten was considered but eventually discarded because the

large number of assumptions needed to do so greatly diminished the reasonableness of the results.

Excel's Operations Management (OM) was the result of a search to find software capable of resolving a facility layout problem with 15 components. This software checked all pairwise comparisons to find the minimum score/flow-distance value [6]. It did not require any installation from disk, as it was downloadable from the Internet. Furthermore, it worked in Microsoft Excel as in add-in. Most importantly, it allowed the user to enter data for 15+ components. Yet for all of the apparent advantages of Excel OM, its disadvantages were tremendous. OM used all of the processing capability of a Pentium III, 233 MHz computer(Figure 2).

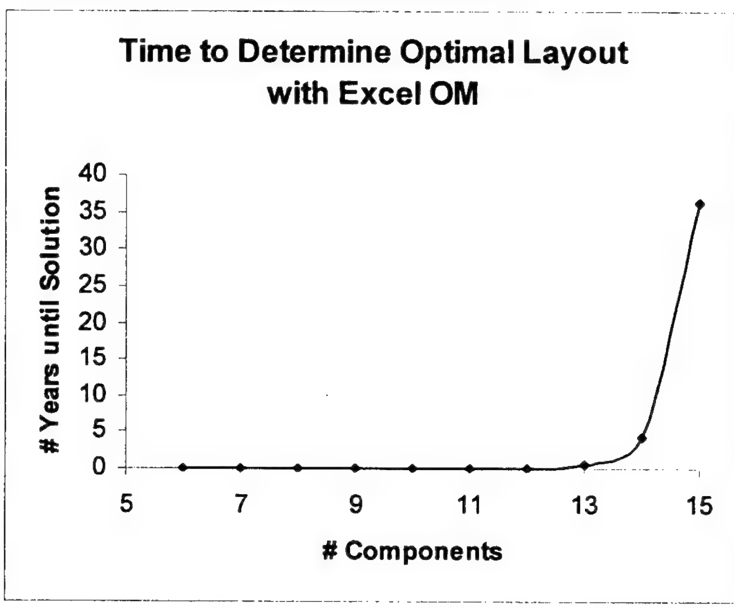

Figure 2.

Attempting another task at the same time as resolving a layout prevented the user from getting back to the program before it finished. Since any layout with greater than 9 facilities

caused Excel OM to crash, changing the active screen with even 10 facilities caused all results to be lost. Even if Excel OM had performed properly, resolving an optimal layout for 15 components would have taken nearly 35 years (see figure 2). Thus, Excel OM was not the answer to modeling an optimal base camp layout.

The final attempt at modeling an optimal camp layout used the Computerized Relative Allocation of Facilities Technique (CRAFT) [7]. This software, also downloadable from the Internet, operated as an Excel add-in. The major advantage of CRAFT was that it could handle a layout with over 40 components. The end result of CRAFT's optimization efforts was a colored display of the determined layout. However, optimality was not guaranteed and the layout was somewhat dependent on the initial layout entered into the software. Additionally, if a facility was created with an area greater than 2x1, its shape might change during the optimization process [8]. This package was a compromise between the ability to handle a large amount of data and guaranteed optimality. For our purposes of determining general proximity relationships between facilities and developing an effective methodology for determining the optimal base camp, CRAFT was sufficient and preferred over the other available alternatives.

MODEL INPUTS AND ASSUMPTIONS

The inputs required for CRAFT were a score (or from-to) matrix, the size of each facility and the overall base camp, and an initial layout. To create the score matrix, the data in the relationship chart was quantified. Although some flow between various departments usually gets entered into this matrix, the proximity relationship data represented the desire for adjacency in a similar manner. The convention used for this process was to code A to 6, E to 5, I to 4, O to 3, U to 2, and X to 1. The area entered for each facility was one unit squared, or one cell. The motivation for this was preventing the shapes of the facilities from changing drastically. Also,

the size of most components depends on the number of troops stationed at the base camp and terrain. The primary goal of this project was not to develop an optimal layout for a specific scenario but to determine proximity relationships between base camp facilities. Since each of the fifteen components was modeled as a single cell, the layout of the camp had an area of 15 units2 (5 x 3 units). The final input for CRAFT was an initial layout. To prevent bias based on knowledge of existing base camps, the components were not entered in any particular order. However, the Mean, Median, and Mode models all had the same initial layout.

Like any other modeling tool, using CRAFT required the formation of modeling assumptions. The two largest assumptions were that terrain did not affect the layout and that size and shape of all facilities was equal. In base camp design, terrain cannot be ignored. Instead of leveling hills, blasting mountains, or rerouting rivers, to create a perfectly flat area, engineers usually change their layout to fit the terrain, not vice-versa. The similar size and shape assumption impacted the optimized layout results. For instance, the area of a base camp devoted to seahut clusters is much greater than the area devoted to an education center. Making this assumption meant that the results did not represent the ideal layout of a base camp so much as it represented the relative importance of facility adjacency. Other assumptions were that not including mail rooms, concession areas, unit facilities, and others did not affect the generated layouts, similar components such as individual seahuts and MWR facilities could be lumped together, and that there were relative and rectilinear distances between components.

ANALYSIS OF RESULTS

Three methods were used to analyze the results from CRAFT. The first was a comparison of the three generated layouts to each other. From this type of analysis, general trends about proximity relationships were discovered as well as a few potential abnormalities.

The second method was a comparison of the layouts to base camp drawings in the Theater Construction Management System (TCMS) [9]. Military engineers use this software to aid in constructing base camps throughout the world. The final analyzation method compared the CRAFT layouts to Camp Bondsteel, a two-year-old base camp in the Balkans. Another method that was considered but ultimately not used because of installation problems was the Consequence Assessment Tool Set (CATS) [10]. This software could have been used to conduct risk analysis on the base camp layouts using both natural and man-made disasters.

DISCUSSION OF RESULTS AND ANALYSIS EFFORTS

In comparing the layouts that CRAFT generated, some general conclusions were made. In each of the layouts, certain components were always adjacent. These components were the dining facility and seahut clusters, motorpool and aviation facility, motorpool and aid station, and the Morale, Welfare, and Recreation (MWR) facilities and the education center. Insights into the positioning of components within a base camp were also gained. Seahut clusters were centrally located in each of the three layouts, the fuel storage area and Post Exchange (PX) were located furthest from the motorpool and aviation facility, and the dining facility, education center, SSA facility, postal facility, MWR facilities, laundry collection point, & aid station were always located near the base's center. Overall, the layouts were not drastically different. Of the components that were adjacent, more than half were adjacent in more than one layout. Figure 3 shows the number of times that facilities were adjacent in the three CRAFT layouts. There were unexpected outcomes such as the PX being located on the corner of the camp in every layout and the dining facility and fuel storage area being adjacent in one layout. For the most part though, the layouts appeared reasonable.

#	Component	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Seahut Clusters															
2	Motorpools															
3	Aviation Facilities		3													
4	Ammo Holding Area		2	1												
5	Mess Halls	3														
6	Chapels					2										
7	Education Center	1					1									
8	Postal Facility	1		1		1		2								
9	SSA Facility	1			2		1	1	2							
10	Personal Services Centers	2								1						
11	PX						1	1			2					
12	MWR Facilities	2					1	3			2	2				
13	Fuel Storage Area					1	2		1		2					
14	Laundry Collection Point			2	1	2		1	1							
15	Aid Station	2	3				1		1	2					2	

Figure 3: Number of Time that Components were Adjacent in CRAFT Layouts

The second tool used to analyze the layouts was a comparison to base camp drawings generated for the Theater Construction Management System. The goal was to contrast and compare what TCMS considered optimal layouts in the mid-1980s with our layouts. The difficulty with using TCMS in this way was that the drawings were static. While the user could modify the components of the base camp and retrieve an updated project plan, the drawings themselves were not updated. Thus, limited comparisons could be made. The drawings were basic and did not include a majority of the facilities such as education centers, fuel storage areas, and MWR sites used in our study. One generality noted from TCMS and our layouts was that the dining facilities were adjacent to the seahuts clusters. However, the seahut clusters were not in the center of the camp. TCMS had helipads in the middle. The CRAFT generated layouts had aviation facilities on the camp's perimeter.

The final analysis method was a comparison of the CRAFT layouts to Camp Bondsteel, which was constructed in 1999. Bondsteel is considered by many to be a model base camp since it is relatively new and the beneficiary of reviews of older camps in the Balkans. Adjacent

facilities in Bondsteel were recorded and compared to the adjacent facilities from the generated layouts. A summary of the findings appears in figure 4.

#	Component Name	Camp Bondsteel						
1	Seahut Clusters	**5**	6	***7***	***10***	11	***12***	***15***
2	Motorpools	**3**	9	10	11	12		
3	Aviation Facilities	**2**	15					
4	Ammo Holding Area							
5	Mess Halls	**1**						
6	Chapels	1	**7**					
7	Education Center	**1**	**6**					
8	Postal Facility	-	-	-	-	-	-	-
9	SSA Facility	2						
10	Personal Services Center	***1***	2	***11***	15			
11	PX	1	2	***10***	15			
12	MWR Facilities	***1***	2					
13	Fuel Storage Area							
14	Laundry Collection Point	-	-	-	-	-	-	-
15	Aid Station	***1***	3	11				

Figure 4: Adjacent Facilities in Camp Bondsteel

CRAFT adequately modeled many facility adjacencies found at Camp Bondsteel. Of the items adjacent to the seahut clusters at Bondsteel, CRAFT modeled 71% correctly and positioned them in the same relative position. The two layouts were also similar in that they each had the fuel storage area, aviation facility, and ammo holding area removed from center of the camp. Additionally, seahut clusters and soldier support facilities were adjacent in both layouts.

The Bondsteel-CRAFT comparison also highlighted some shortcomings of our models. CRAFT identified only 20% of those facilities adjacent to motorpools. This occurred because there were over 20 separate motorpools throughout Camp Bondsteel while in the CRAFT layouts, there was only one component representing a motorpool. Thus, it appears that our method had a difficult time dealing with multiple component adjacencies. Also, the CRAFT layouts did not express the actual distance between facilities well. For instance, the ammunition

holding and fuel storage areas at Camp Bondsteel were separated from any other facility by hundreds of meters. Although the CRAFT layouts show that these components should be on the periphery of the camp, they did not show the need to separate them from adjacent components significantly. The final shortcoming the Bondsteel comparison showed was that the generated layouts did not express the relative size of the facilities. In the CRAFT layouts, each component's area was a single cell. Thus, a maximum of four components could be adjacent to a cell in a given layout. At Bondsteel, the seahut clusters had 7 adjacent components because it had a larger perimeter than other facilities such as chapels and education centers. Thus, a single CRAFT layout could account for no more than four of the seven adjacencies found at Bondsteel. Although CRAFT didn't identify all of the adjacencies of larger facilities, it did identify which of the facilities had the strongest proximity relationships.

Overall, the CRAFT layouts modeled 49% of the facility adjacencies found at Camp Bondsteel. Of the adjacencies not identified by CRAFT, over 41% were related to the PX and motorpools. Excluding the seemingly inadequate modeling of these facilities, nearly 60% of the facility adjacencies in Bondsteel were determined by CRAFT.

RECOMMENDATIONS FOR FUTURE WORK

After finishing the modeling methodology described in this paper, there appear to be numerous areas for expansion and future work. First, contact with more stakeholders is needed. Developing any degree of statistical stability requires more than the 12 respondents who filled out the online survey. Additionally, the survey itself should be expanded to include questions about the proximity relationships of more facilities such as finance centers, unit areas from battalion to task force level, power plants, wastewater facilities, and concession areas. However, each additional component greatly increases layout computation time. Given the inputs of camp

size and population, an algorithm that could recommend the size and number of components would also be useful in developing a basic optimal camp layout. Before putting the facilities in an optimal position however, terrain must be considered. It is extremely unlikely that a base camp will be built without any geographical or geological limitations. Possible techniques for doing this include the software packages GEOBest and LOGSPOT. The user of a future system should also have the capability to enter hard constraints such as "seahut clusters and fuel storage areas must be non-adjacent" before optimizing the base camp layout.

After the base camp layout had been determined, some type of sensitivity analysis on the initial layout in CRAFT should be conducted to check if the generated layout is strongly dependent on the initial layout. Afterwards, risk analysis should be conducted to aid in determining if the layout is truly optimal. The Probabilistic Risk Assessment and Management (PRAM) and CATS are two possible risk management software packages.

A decision support system for Army engineers with these changes implemented would be a powerful tool. An engineer could enter values for the camp size and population, terrain limitations, and hard constraints he wants to obtain a layout that is an 80-90% solution in a matter of minutes. This would help greatly to reduce planning time and give engineers a base case from which to construct a base camp.

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